# Forecasting Scour Related Mine Burial Using a Parameterized Model

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Award Number: N00014-03-1-0298
http://www.vims.edu/~cfried/MBP

## LONG-TERM GOALS

A major goal of the ONR Mine Burial Prediction (MBP) Program is to provide the operational Navy a prototype model for forecasting mine burial which works with a known and useful degree of accuracy in regions of strategic interest, defined initially as sandy inner shelves dominated by waves. In order to be useful under real world conditions, such a model must be reasonably accurate and reliable but also simple and fast enough to execute in a practical, straightforward manner by the Fleet. Thus it must parameterize the complicated and computationally intensive details of localized mine scour. In response to the above needs of the operational Navy, the long-term goal of this project is to demonstrate the practical utility of forecasting scour related mine burial using a simple parameterized model forced by readily available wave, wind and tidal forecasts.

## OBJECTIVES

This project has the following specific objectives: 1. Post on the web continuous five-day forecasts of hydrodynamic variables for the MBP field sites, including wave height, period and direction, near-bed rms wave orbital velocity, wind speed and direction, wind-driven current speed and direction, tidal current and direction, and combined wave-current bed stress. 2. Predict scour-induced mine burial for the MBP field sites using a parameterized model and post continuously updated five-day forecasts of mine burial to the web. 3. Extend the parameterized model for scour burial to encompass additional new and existing field and laboratory data.

## APPROACH

Our approach in forecasting wave conditions at the MBP field sites is to transform forecasts from the nearest grid cell locations provided by the NOAA Wavewatch III (WW3) global wave model. The WW3 model provides five-day forecasts of winds and waves in the northwest Atlantic with 0.25 degree resolution in latitude and longitude. We then use empirical transformations based on historical time-series of measured wave conditions at the MBP field sites to translate the model forecasts to local conditions. Tidal currents are forecast based on harmonic analyses of existing current observations. Wind driven currents are forecast from WW3 wind predictions by applying empirical correlations developed from correlations between WW3 hindcast winds and de-tided current observations.

Our approach in predicting mine burial is to apply well-established engineering relations for scour around seabed objects as developed in the academic literature (Soulsby, 1997; Whitehouse, 1998). For energetic scour, these relations predict

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE<br>**30 SEP 2003** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2003 to 00-00-2003** |

4. TITLE AND SUBTITLE
**Forecasting Scour Related Mine Burial Using a Parameterized Model**

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
**The College of William and Mary,,School of Marine Science, Virginia Institute of Marine Science,,Gloucester Point,,VA,23062**

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT
**A major goal of the ONR Mine Burial Prediction (MBP) Program is to provide the operational Navy a prototype model for forecasting mine burial which works with a known and useful degree of accuracy in regions of strategic interest, defined initially as sandy inner shelves dominated by waves. In order to be useful under real world conditions, such a model must be reasonably accurate and reliable but also simple and fast enough to execute in a practical, straightforward manner by the Fleet. Thus it must parameterize the complicated and computationally intensive details of localized mine scour. In response to the above needs of the operational Navy, the long-term goal of this project is to demonstrate the practical utility of forecasting scour related mine burial using a simple parameterized model forced by readily available wave, wind and tidal forecasts.**

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **9** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

$$S = S_{inf} (1 - \exp(t/T)), \quad (1)$$
$$S_{inf} = 0 \text{ for } U_b < 0.75\, U_{cr}, \quad (2a)$$
$$S_{inf} = 1.15\, D\, (2\, U_b - 1.5\, U_{cr})/U_{cr} \text{ for } 0.75\, U_{cr} \le U_b < 1.25\, U_{cr}, \quad (2b)$$
$$S_{inf} = 1.15\, D \text{ for } U_b \ge 1.25\, U_{cr} \quad (2c)$$

where $S_{inf}$ is the final depth of scour, t is time, and T is a time-scale factor which, in turn, is a function of dimensionless numbers characterizing the environmental forcing, D is mine diameter, $U_b$ is the far-field velocity above the mine, and $U_{cr}$ is the critical velocity for the initiation of motion of non-cohesive sand given by Soulsby (1997) as a function of sand size and density. Following Whitehouse, the time-scale factor in (1) is given by

$$T = 0.095\, \square^{-2.02}\, D^2\, [g(s-1)d^3)]^{-1/2}, \quad (3)$$

where $\square = u_*^2\, [g(s-1)d]^{-1}$ is the Shield's parameter, g is the acceleration of gravity, s is the weight of sand relative to water, d is grain size, $u_* = (f_w/2)^{1/2} U_b$ is the skin-friction shear velocity, and $f_w$ is the wave friction factor associated with skin friction.

Depth of burial is related to, but distinct from, depth of scour. Based on the observations of Richardson and Traykovski (2002), a cylindrical mine on a sandy inner shelf buries by repeatedly falling into its own scour pit. Thus the depth of burial of a mine relative to the undisturbed far-field bed is given approximately by the maximum depth of scour, $S_{max}$, experienced to that point by the mine. Another important result of Richardson and Traykovski is that growing waves can partially unbury a previously buried mine. Thus we define instantaneous mine burial depth, B, as

$$B = S_{max} (1 - \square S/S_{max}) \quad (4)$$

where $\square$ is a factor (between 0 and 1) that parameterizes the efficiency with which scour re-exposes the mine while the mine simultaneously settles into its scour pit. Finally, percent burial by surface area is calculated by relating B to the exposed surface area of a circle submerged to depth B. A 100% maximum and 10% minimum are also included because no more than 100% of a mine can be buried, and observations from Martha’s Vineyard indicate at least 10% of a mine is always in contact with the bed.

## WORK COMPLETED

We have established a website (www.vims.edu/~cfried/MBP) where we provide continual five-day forecasts of hydrodynamic conditions and mine burial for both the Indian Rocks Beach (IRB) and Martha’s Vineyard Coastal Observatory (MVCO) field sites. The results of our collaborative work on mine burial prediction were presented at several venues in FY03 (Briggs et al., 2003; Elmore et al., 2003; Richardson et al., 2003; Trembanis et al., 2003). In particular, at the 2003 ONR Mine Burial Prediction Meeting in St. Petersburg, Florida, we presented forecasts of mine burial while instrumented mines were in the water offshore (Friedrichs and Trembanis, 2003). We were the only MBP investigators to provide real-time forecasts of mine burial during the field experiment. To demonstrate the potential for rapid response to operational needs, we also added a web page with similar forecasts of mine burial for the northwest Persian Gulf during the early stages of Operation Iraqi Freedom.

## RESULTS

Five-day forecasts of the WW3 model have been downloaded and archived at our website twice daily

since September 2002. Using a linear transformation from the nearest model grid point, hindcasts by this model adequately reproduce wave height at the ONR MBP field areas (Figure 1). The parameterized burial model has been successfully calibrated using WW3 wave model output and observations from current meters and instrumented mines deployed at the Martha's Vineyard field site (Figure 2). We are initially using a constant wave period and linear wave theory with an empirical correction to predict bottom orbital velocity. We then apply a constant friction factor to predict skin friction. A running hindcast and five-day forecast of post-impact mine burial by wave-induced scour, based on the Martha's Vineyard calibration, was produced for the Indian Rocks Beach site (Figure 3).

The Indian Rocks Beach mine burial forecasts were begun before instrumented mines were deployed at the site, and ongoing forecasts were updated every 12 hours. Differences between successively forecast and hindcast wave heights lead to significant differences between forecast and hindcast mine burial (Figure 3). Nonetheless, it is encouraging that errors in the mine burial model may not be the largest source of overall uncertainty in burial forecasts. The parameterized model predicts rapid scour for increasing orbital velocity ($U_b$) once $U_b$ exceeds 1.25 times the critical velocity for initiation of grain motion ($U_{cr}$). Rapid burial follows once $U_b$ drops below 0.75 $U_{cr}$. Forecasts of wave height, bottom orbital velocity, wind and mine burial over the entire course of the field experiment are available for download via the VIMS MBP web site at www.vims.edu/~cfried/MBP.

A 2-D interactive GUI interface for the ~1 km$^2$ IRB field site is available via the web that allows users to rerun any portion of the numerical experiment for any geographic point within the field area (Figure 4). The 2-D interactive model includes spatially varying bathymetry and grain size along with temporally varying wave height. Users can specify mine diameter and globally vary both wave height and grain size to further examine model sensitivity. Since operational Fleet needs often depend on several metrics for describing mine burial, we report both percent exposed surface area and the depth of the mine relative to the far field ambient seabed level. Movies of our 2-D "best model prediction" for the completed MBP field experiments at IRB (Jan-Mar 2003) and at MVCO (Jan 2002) can be viewed at www.vims.edu/physical/projects/CHSD/projects/MBP/ONR03_report.

In preparation for the MVCO field experiment in FY04, we have developed an empirical model to forecast tide and wind-driven currents at MVCO. Future tidal currents were forecast based on a least-squares harmonic analysis of current observations collected at MVCO in 2002, and hourly predicted tidal currents for 2001 to 2004 are now on our website. The along-shore component of hindcast wind stress from the WW3 model for 2002 was then regressed against the along-shelf component of the tidal residual current to develop a predictive model for the along-shelf wind-driven current. Figure 5 displays a comparison of observed and hindcast along-shelf currents at MVCO for all of 2002. We are about to add five-day forecasts of along-shelf wind-driven currents for MVCO to the website.

**IMPACT/APPLICATIONS**

Our work with the Soulsby-Whitehouse equations has already impacted the strategy being taken by others to provide a working mine burial model for the operational Navy. Our MatLab formulation of the governing equations has been passed on to Paul Elmore at NRL, who is incorporating them in his prototype linked modeling system, and to Alan Brandt and Sarah Rennie at Johns Hopkins, who are incorporating the equations into their prototype expert system. Based on our early success with this simple parameterized approach at the MBP field sites, it is likely that the new model ultimately used for scour-induced burial by the operational Navy will build directly on our formulation.

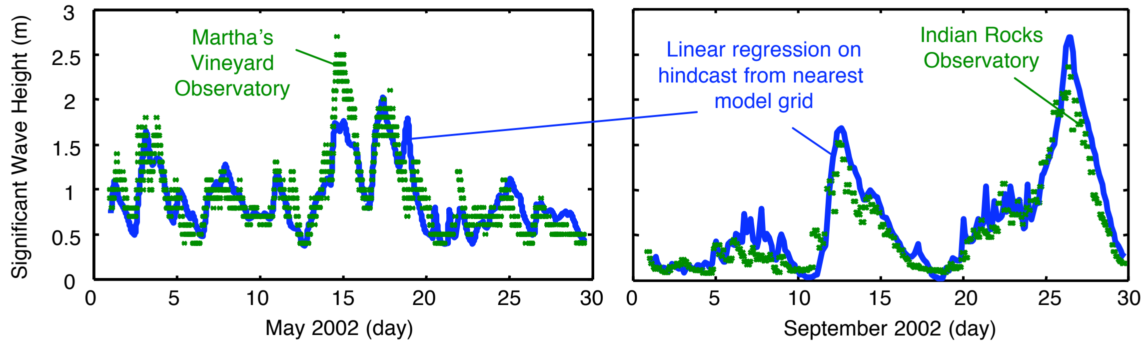


***Figure 1. Time-series of significant wave heights at Martha's Vineyard and Indian Rocks compare well with linear transformations from nearest NOAA WW3 grid points.***

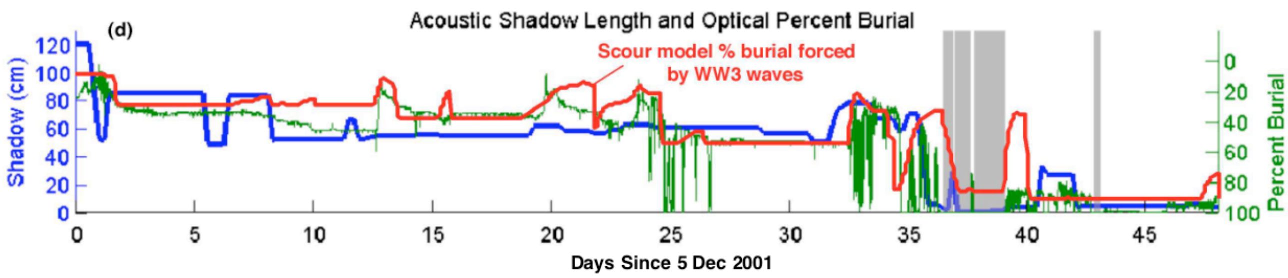


***Figure 2. Percent burial predicted by the parameterized model forced by WW3 waves compares well to mine burial observed at MVCO by Richardson and Traykovski (2002).***

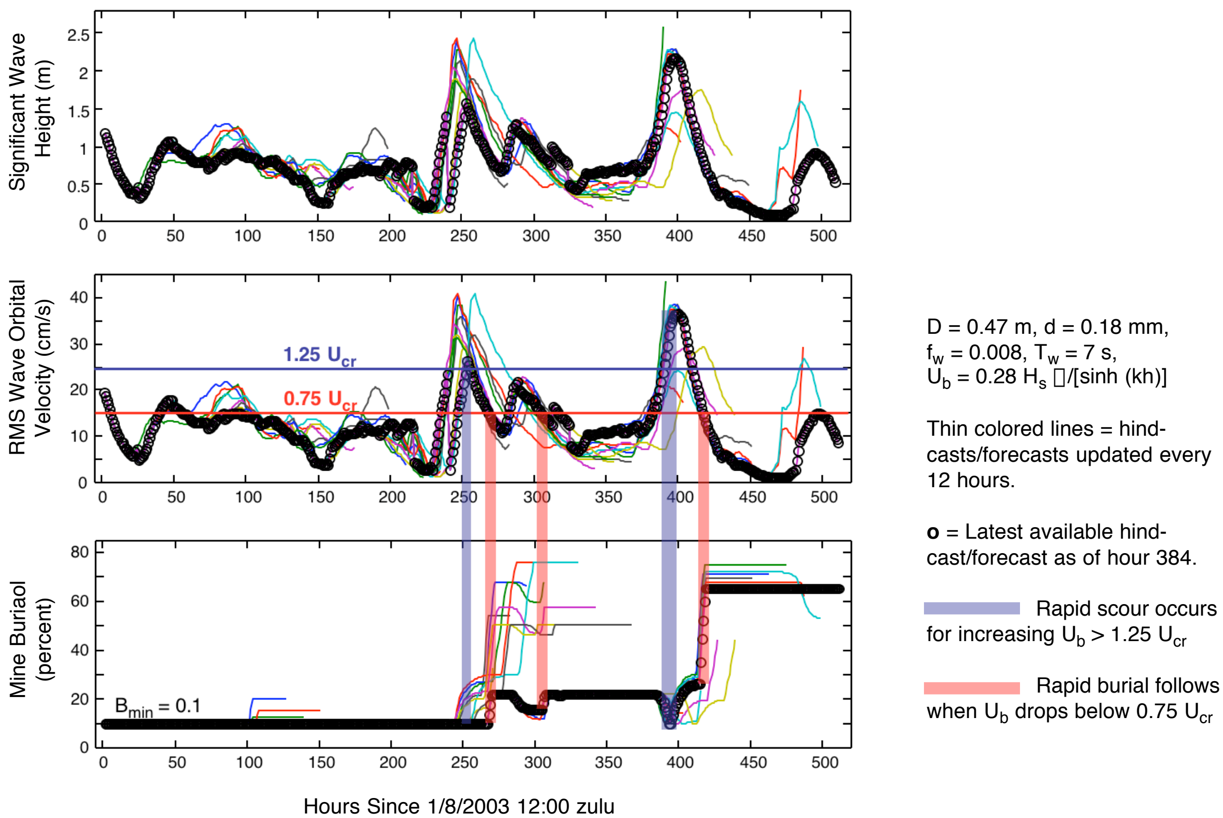


***Figure 3. Hindcast/forecasts of waves and burial for Indian Rocks site presented at MBP Annual Meeting during field experiment. At hour 384, 65% burial was forecast for hour 500.***

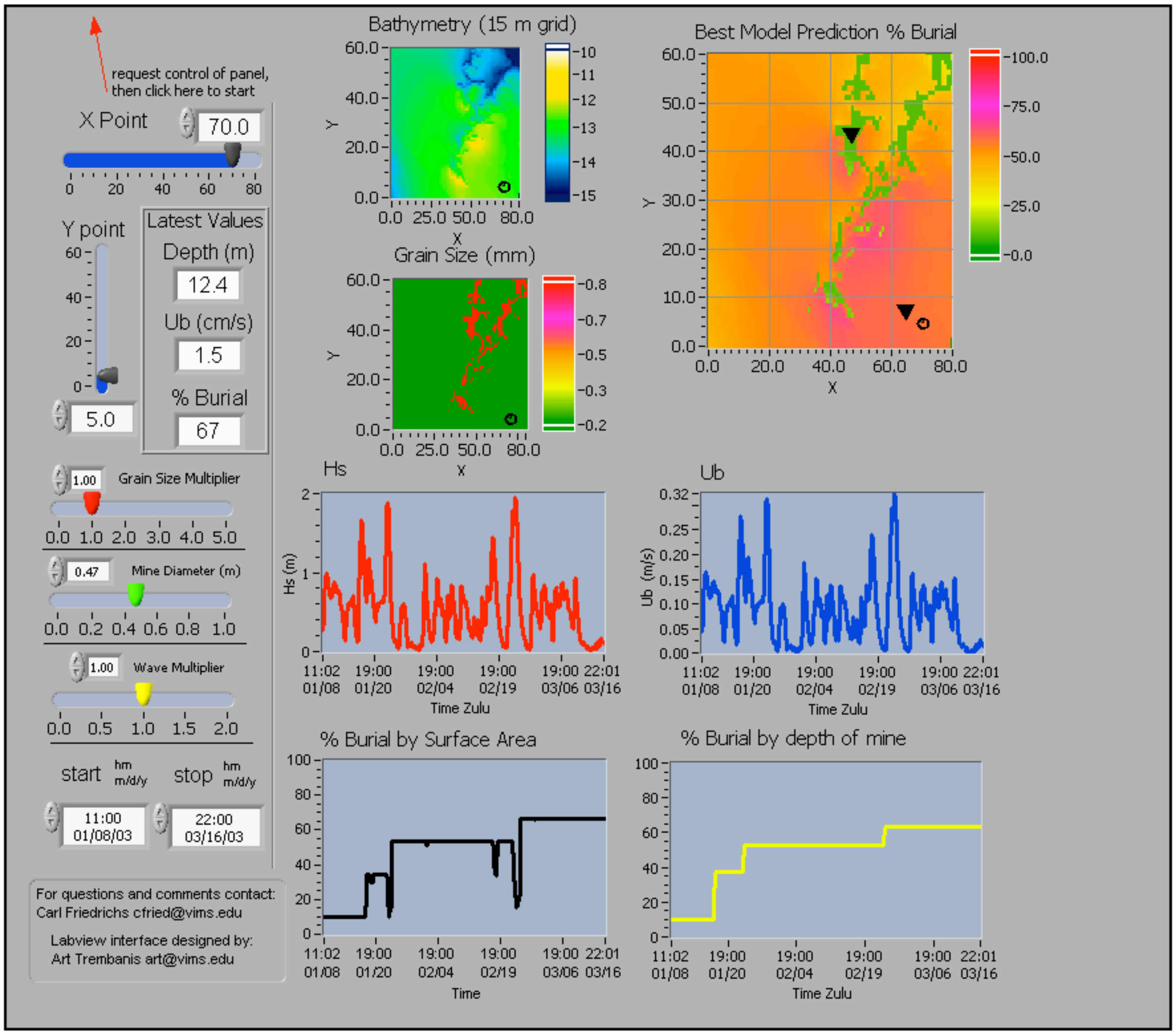


*Figure 4. GUI interface for interactive 2-D model for mine burial at the Indian Rocks field site. Any recent PC or Mac with high-speed internet access can run this model via the web.*

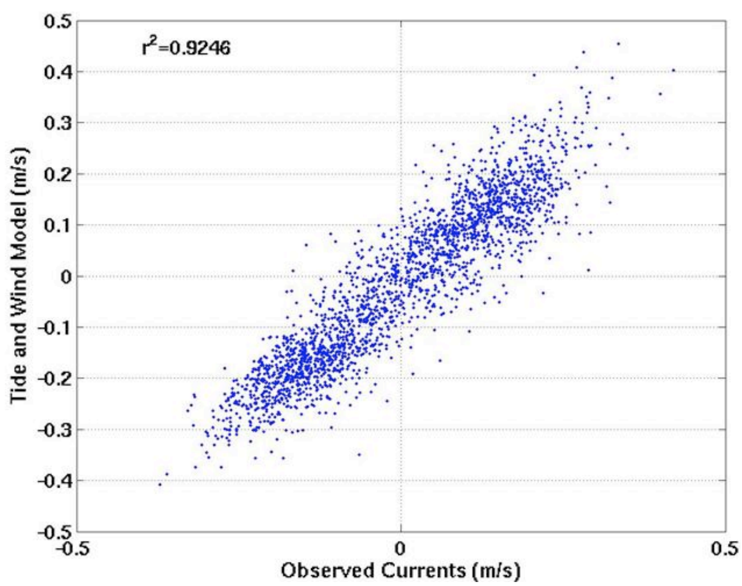


*Figure 5. Most of the variance in the observed along-shelf current can be explained by a tidal harmonic analysis in combination with a residual current forced by WW3 model winds.*

## TRANSITIONS

During the month of September 2003, our mine burial prediction website at VIMS was visited by nearly 3000 unique users from 43 countries. The top ten countries in order of decreasing number of hits were: United States, Canada, Japan, United Kingdom, Australia, Taiwan, Sweden, Finland, Netherlands, and Hong Kong. In addition, we have been corresponding one-on-one with Phil Mulhearn at the Australian Defence Science and Technology Organisation. As part of his own research into scour-induced mine burial, Dr. Mulhearn has begun comparing the output of our model to Marcelo Garcia's recent laboratory experiments on scour-induced burial of cylinders by waves.

## RELATED PROJECTS

The following recent projects involving Friedrichs also focus on coastal sediment transport:

1. Upscaling Simple Models for Energetic Shelf Sediment Transport. Office of Naval Research (www.vims.edu/physical/projects/CHSD/projects/Euro).

2. Sediment Dynamics of a Microtidal Partially-Mixed Estuary. National Science Foundation (www.vims.edu/physical/projects/CHSD/projects/CAREER).

3. The Role of Spatially Complex Shoreface Roughness in Sediment Transport and Deposition: A New Zealand Case Study and Model Development. National Science Foundation. (www.vims.edu/physical/projects/CHSD/projects/NewZealand).

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Elmore, P.A., C.T. Friedrichs, M.D. Richardson, P.A. Traykovski, and K.B. Briggs, 2003. Comparison of Wallingford (DRAMBUIE) scour predictions with measurements. ONR Mine Burial Prediction 3rd Annual Meeting, St. Petersburg, FL, 28-29 January

Friedrichs, C.T., and A.C. Trembanis, 2003. Forecasting scour related mine burial using a parameterized model. ONR Mine Burial Prediction 3rd Annual Meeting, St. Petersburg, FL, 28-29 January.

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Richardson, M.D., G.R. Bower, K.B. Briggs, P.A. Elmore, C.S. Kennedy, P.J. Valent, D.F. Naar, S.D. Locker, P. Howd, A.C. Hine, B.T. Donahue, J. Brodersen, T.F. Wever, R. Luehder, C.T. Friedrichs, A.C. Trembanis, S. Griffin, J. Bradley, and R.H. Wilkens, 2003. Mine burial by scour: Preliminary results from the Gulf of Mexico. Oceans 2003 Marine Technology and Ocean Science Conference, San Diego, CA, 22-26 September.

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**HONORS/AWARDS/PRIZES**

Friedrichs, C.T., 2000. Faculty Early Career Development (CAREER) Award. Awarded by the National Science Foundation (NSF). Description from NSF website: The CAREER Award is NSF's most prestigious award for new faculty members. The CAREER program recognizes and supports the early career-development activities of those teacher-scholars who are most likely to become the academic leaders of the 21st century.

Friedrichs, C.T., 2000. Presidential Early Career Award for Scientists and Engineers (PECASE). Awarded by President Clinton. Description from PECASE website: The PECASE Award is the highest honor bestowed by the United States government on young professional at the outset of their independent research careers. Eight Federal departments and agencies join together annually to nominate the most meritorious young scientist and engineers who will broadly advance the science and technology that will be of the greatest benefit to fulfilling the agencies' missions.

Friedrichs, C.T., 2001. Class of 1964 Distinguished Professorship. Awarded by the College of William and Mary. From William and Mary memo: Distinguished professorships for associate professors are designed to recognize and reward excellence in research or creative activity and a demonstrated commitment to teaching, and to encourage faculty to remain at the College. Recipients of these professorships will already enjoy a reputation for excellence in scholarship and teaching which suggests that they may be candidates for other distinguished professorships in the future.